Cooling Water Corrosion

Corrosion

Program Topics:

- Consequences
- Mechanisms
- Factors Affecting
- Metal Failures
- General Control
- Inhibitors
- Program Choice
- Control
- Pretreatment
- Norms & Economics

Consequences of Corrosion

- **Reduced Heat Transfer (Lost Efficiency)**
- **Increased Cleaning (Added Costs and Hassle)**
- **Equipment Repair and Replacement (Lost Revenue)**
- **Process or Water-Side Contamination (Poor Product Quality)**
- **Unscheduled Shutdown (Lost Revenue)**

Introduction

Corrosion -

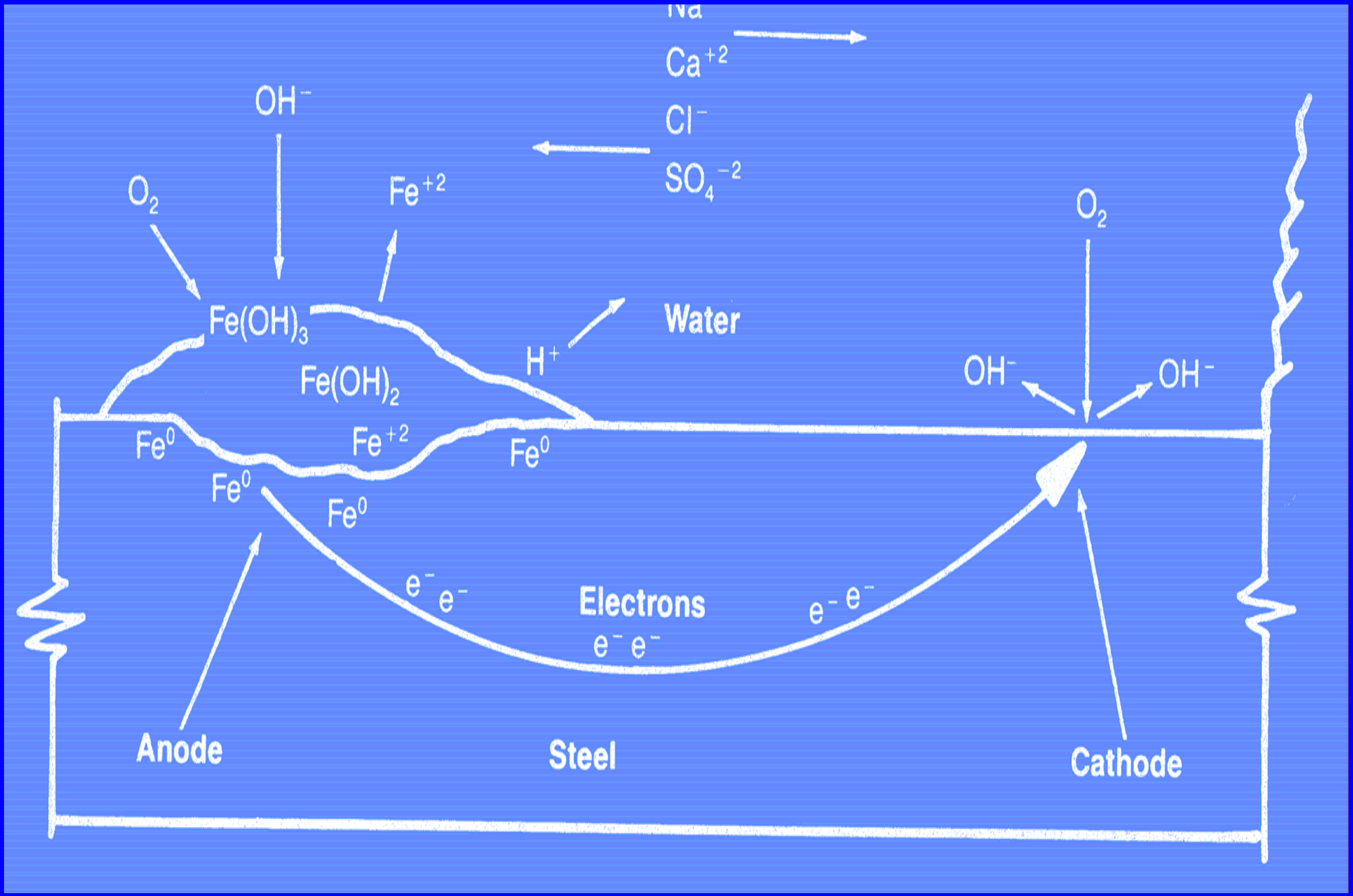
An electrochemical process in which a metal in it's elemental form returns to it's native (i.e., oxidized) state.

The Corrosion Cell

The following elements are required for corrosion to occur:

- **A corrodable surface - one with electrons to lose**
- **A difference in potential - a driving force for the electrons**
- **An electron acceptor - a place for the electrons to go**
- **An electrolyte, to close the circuit - conditions conducive for electron flow**

The Corrosion Cell



The Corrosion Cell

The Rate of Corrosion is Determined by Reactions at the Cathode:

- **Size of the Cathode**
- **Amount of Oxidizer at the Cathode**
- **Polarization (the size of the potential difference)**
- **Temperature**
- **Water Velocity**
- **pH**
- **Dissolved Gases**

The Corrosion Cell

The Type of Corrosion is Determined by the Environment at the Anode:

- Chemistry Anomalies
  - Differential Ion Cells
  - Differential Oxygen Cells
- Surface Anomalies
  - Deposits
  - Surface Imperfections
  - Dissimilar Metals

Galvanic Series

Active End (Anode)

Magnesium
Magnesium Alloys
Zinc
Galvanized Steel

Aluminum 1100

Aluminum 6053
Alclad

Cadmium

Aluminum 2024 (4.5 Cu, 1.5 Mg, 0.6 Mn)

Mild Steel
Wrought Iron
Cast Iron

13% Chromium Stainless Steel
  Type 410 (Active)
18-8 Stainless Steel
  Type 304 (Active)
18-12-3 Stainless Steel
  Type 316 (Active)

Lead-Tin Solders
Lead
Tin

Muntz Metal
Manganese Bronze
Naval Brass

Nickel (Active)
76 Ni - 16 Cr - 7 Fe Alloy (Active)

60 Ni - 30 Mo - 6 Fe - 1 Mn

Yellow Brass
Admiralty Brass
Aluminum Brass
Red Brass
Copper
Silicon Bronze

70:30 Cupro Nickel
G-Bronze
M-Bronze
Silver Solder
Nickel (Passive)
76 Ni - 16 Cr - 7 Fe
  Alloy (Passive)
67 Ni - 33 Cu Alloy (Monel)

13% Chromium Stainless Steel
  Type 410 (Passive)
Titanium

18-8 Stainless Steel
  Type 304 (Passive)
18-12-3 Stainless Steel
  Type 316 (Passive)

Silver

Graphite
Gold
Platinum

Noble or Passive End (Cathode)

Types of Cooling Water Corrosion

- **General Etch**
- **Concentration Cell Corrosion**
- **Cracking**
- **Mechanical Damage**

Types of Cooling Water Corrosion

- **General Etch**

Metal loss in which a given area is alternately a cathode and an anode. Metal loss occurs uniformly over the entire surface.

This is the preferred type of corrosion.

Types of Cooling Water Corrosion

- **Concentration Cell Corrosion**

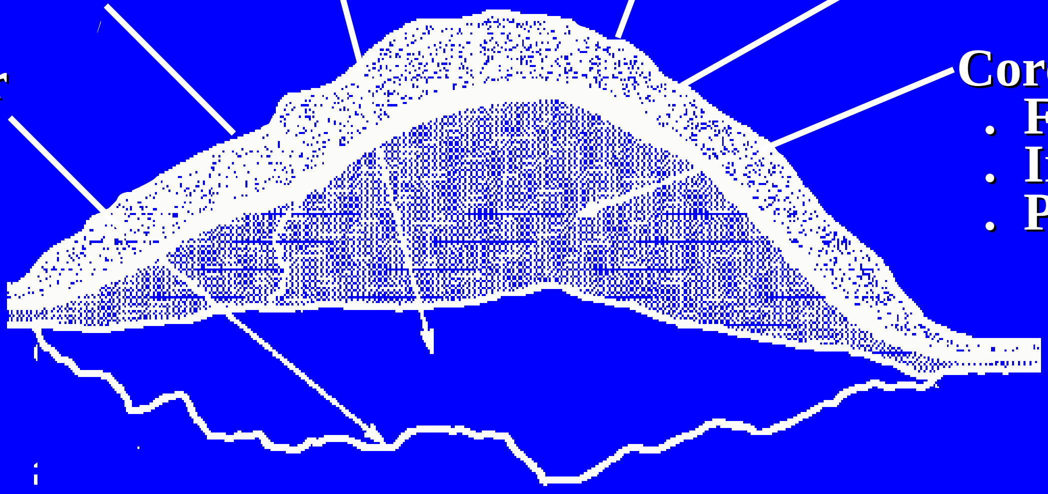
A localized attack caused by a chemical anomaly.

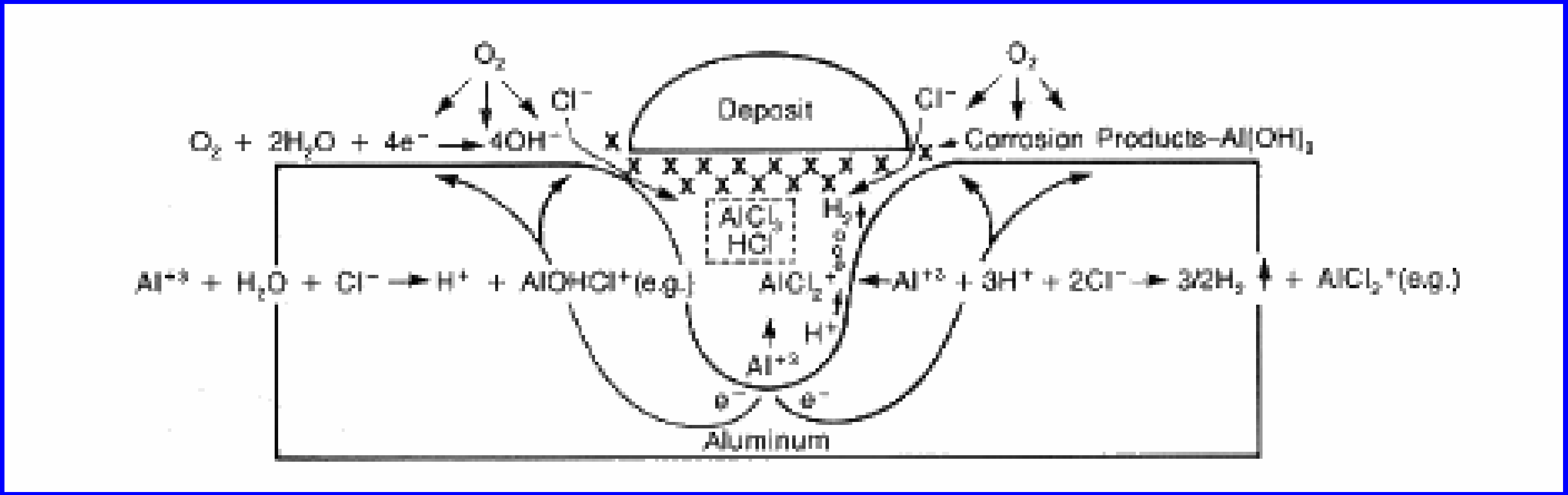
- **Crevice Corrosion**
- **Under Deposit Corrosion**
- **Tuberculation**
- **Biologically Induced Corrosion**
- **Acid or Alkaline Corrosion**

Types of Cooling Water Corrosion

- **Tuberculation**

Highly structured mounds of corrosion products that cap localized regions of metal loss





O2
Cl−
Deposit
Cl−
O2
O2 + 2H2O + 4e− → 4OH−
Corrosion Products–Al(OH)3
AlCl3
HCl
H2
Al+3 + H2O + Cl− → H+ + AlOHCl+(e.g.)
AlCl2+
Al+3 + 3H+ + 2Cl− → 3/2H2 + AlCl2+(e.g.)
H+
Al+3
e−
e−
Aluminum

Types of Cooling Water Corrosion

- **Cracking**

Failures caused by the combined effects of corrosion and metal stress. Initiate on the surface exposed to the corrodant, and propagate into the metal in response to the stress state. The critical factors are:

- **Sufficient Tensile Stress**
- **A Specific Corrodant**

Types of Cooling Water Corrosion

Mechanical Damage

- Corrosion Fatigue
- Erosion - Corrosion
- Cavitation
- Dealloying

General Methods for Corrosion Inhibition

- Use Corrosion Resistant Materials
- Apply Inert Barrier or Coating
- Use Cathodic Protection
- Adjustments to Water Chemistry
- Application of Corrosion Inhibitors

Chemical Corrosion Inhibitors

Mechanism

- **Principally Anodic**
- **Principally Cathodic**
- **Both Anodic and Cathodic**

Anodic Inhibitors

Function by adjusting the chemistry at the anode (point of high potential)

- **Chromate**
- **Molybdate**
- **Nitrite**
- **Ortho Phosphate (High Dose)**
- **Silicate**

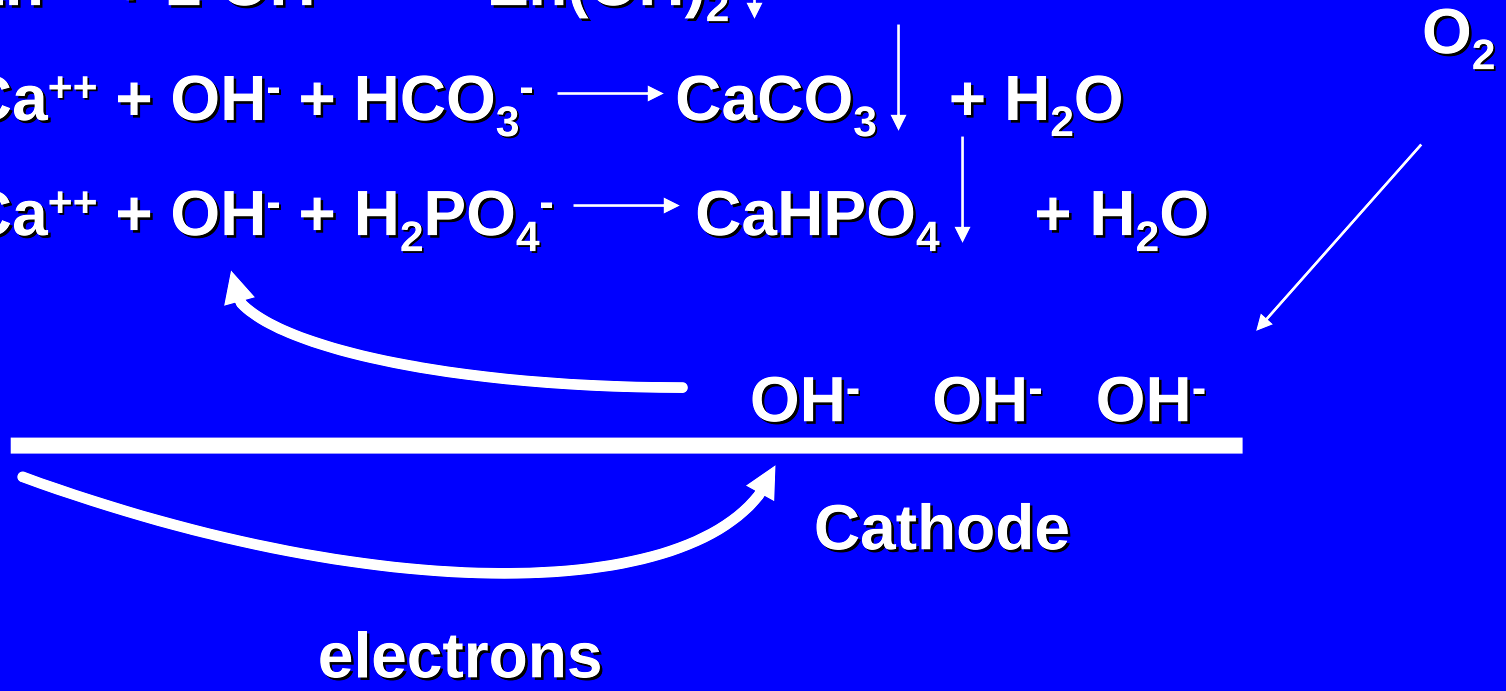
Cathodic Inhibitors

Function via reactions at the cathode (point of high pH)

$$Zn^{++} + 2\,OH^- \longrightarrow Zn(OH)_2\downarrow$$

$$Ca^{++} + OH^- + HCO_3^- \longrightarrow CaCO_3\downarrow + H_2O$$

$$Ca^{++} + OH^- + H_2PO_4^- \longrightarrow CaHPO_4\downarrow + H_2O$$



Cathodic Inhibitors

Function by adjusting the chemistry at the cathode (point of high pH)

- **Zinc**
- **Ortho Phosphate (low dose)**
- **Polyphosphate**
- **Phosphonates**
- **Calcium Carbonate**

Both Anodic and Cathodic Inhibitors

- **Soluble Oils**
- **Azole Filmers**
  - **Mercaptobenzothiazole (MBT)**
  - **Benzotriazole (BZT)**
  - **Tolytriazole (TT)**

Program Choice

Program Selection requires that all technical, environmental and economic needs are met.

- **Environmental Considerations**
- **Make Up Water Chemistry**
- **Possible Contaminants**
- **System Dynamics**
- **Other Program Needs**

Feed and Control

Proper Program Maintenance requires the continuous application of the correct level of inhibitor:

- **Continuous Feed**
- **Routine Testing**
- **Monitoring Program Effectiveness**
  - **Corrosion coupons**
  - **Corrators and Corrosometers**
  - **Total Iron, Copper, etc**
  - **Eddy Current Testing**

Pretreatment

Pretreatment

Purpose -

- **Before a new system is brought on line, or, after an acid cleaning, the system is cleaned with a chemical capable of establishing a passive (i.e., corrosion resistant) film in order to prevent initial damage.**

Pretreatment

Mechanism -

- **Film Formers - Application of high levels of phosphates (poly or ortho) establish a tough iron phosphate film which cleaning oils and residue from the surface.**

- **Passivators - Application of high levels of chromates, nitrites or molybdates establishes a tough iron oxide film which is passive to corrosion.**

Norms & Economics

- **General scale, deposit and corrosion control costs:**

  $75-400/MM # Blowdown

- **Properly Monitored Corrosion Rates**
  - **<5 mpy mild steel (general etch)**
  - **<1 mpy mild steel (with chromate)**
  - **<0.2 mpy copper and copper alloys**
  - **<0.1 mpy on exotic alloys**